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Final Report

A. Grant Title: Dynamical and Chemical Behavior of the Lower Stratosphere and Interactions with the Troposphere

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B. Investigator: Murry L. Salby
Department of Astrophysical, Planetary,
and Atmospheric Sciences
University of Colorado
Boulder CO

Equivalent-barotropic calculations, in tandem with Lagrangian analyses, reveal how changes of total ozone follow from vertical and horizontal transport by planetary waves. Those calculations also throw light on how diabatic motions comprising the Brewer-Dobson circulation develop from quasi-horizontal advection by planetary waves. Potential temperature along a material surface indicates organized subsidence inside the polar-night vortex, resembling tracer observations from UARS. Lagrangian histories illustrate that this sinking motion follows in large part from parcels being driven out of thermodynamic equilibrium by planetary waves, especially at high latitudes. Irreversible heat transfer then produces a net drift of air across isentropic surfaces as parcels orbit about the displaced vortex. By driving mean-meridional overturning in the stratosphere, this downward drift is ultimately responsible for transferring ozone from the tropics to the extratropical lower stratosphere. It also introduces horizontal structure into the distribution of total ozone, which surfaces clearly in ozone trends.

High-resolution global cloud imagery constructed from 6 satellites simultaneously observing the Earth was used to investigate the spectrum of equatorial waves generated by tropical convection and propagating vertically into the stratosphere. The results indicate that temperature variability is dominated by planetary-scale equatorial waves like the Kelvin mode, which agrees with satellite observations of the tropical stratosphere. However, the Kelvin mode accounts for only about 30 – 50% of the eastward momentum flux radiating into the stratosphere, the remainder coming from gravity waves.

An algorithm was developed to determine 3-dimensional atmospheric motion from satellite tracer measurements. Based on Lagrangian constraints, the algorithm circumvents limitations of the traditional scheme for inferring motion from temperature measurements and determines the circulation in the tropics as reliably as elsewhere.

A study of deep convection revealed that the highest towers (those penetrating into stratospheric air and controlling tropopause height and composition through convective mixing) occur in close association with the diurnal cycle of convection. Clouds colder than 220 K develop almost entirely in association with the diurnal cycle of convection over tropical landmasses and substantially in association with it even over maritime regions.

Towards understanding the structure, seasonality, and interannual variation of ozone, we developed a 3-dimensional model of stratospheric transport and photochemistry, one based on the primitive equations in isentropic coordinates. Fully spectral, this mechanistic model is forced by observed tropospheric behavior on an isentropic surface and treats some 50 chemical reactions. The model's development was supported only in part by this funding, which was not continued beyond the present grant. Although subsequent to this grant, that model has since been completed. It has been used along with Lagrangian analyses to study how 3-dimensional transport and photochemical production lead to the observed distribution of total ozone. It has also been used to understand how radiative forcing by Antarctica leads to the cold polar-night vortex, which supports ozone depletion over the South Pole. Future calculations with this model should reveal how interannual changes of ozone are related to changes in tropospheric structure. They will be useful for understanding how nonconservative effects associated with dynamics and photochemistry combine to produce observed variations in total ozone and how those features may evolve in response to long-term changes in tropospheric forcing.

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